WATER RESOURCES RESEARCH, VOL. 37, NO. 11, PAGES 2835–2838, NOVEMBER 2001

Long-term snow database, Reynolds Creek Experimental Watershed, Idaho, United States

Danny Marks, Keith R. Cooley,[1] David C. Robertson, and Adam Winstral

Northwest Watershed Research Center, Agricultural Research Service, U.S. Department of Agriculture
Boise, Idaho, USA

Abstract. Snow is the dominant form of precipitation in the Reynolds Creek Experimental Watershed (RCEW). Water from snowmelt is critical to the ecosystems and resources in RCEW because the water stored in the seasonal snow cover is the primary source of spring and summer soil moisture and streamflow. Snow water equivalent (SWE) has been measured at eight locations in RCEW every 2 weeks throughout the snow season (December 1 to June 1) for 35 water years (1962–1996). SWE was continuously monitored at one reference site for 14 water years (1983–1996). The measurement sites are described, the methods used are presented and discussed, these data are summarized, and examples of how they have been used are presented.

1. Introduction

Water from melting snow is a critical resource in the western United States, Canada, and other similar regions of the world. This is particularly true in the arid watersheds of the interior northwestern United States such as the Reynolds Creek Experimental Watershed (RCEW). In RCEW the storage of winter precipitation in the seasonal snow cover for release during spring and early summer is critical to sustaining the basin's vegetation and ecosystems.

When the northwest hydrology research watershed was authorized by Congress in 1959 and located in the Reynolds Creek basin in the Owhyee Mountains of Idaho in 1960, five essential measurements were defined. One of these was snow [*Robins et al*., 1965, p. 412]: "snow deposition and melt as related to the nature of snowfall, shifting by wind, vegetation, topography, and meteorologic factors." To satisfy this requirement, a series of intensive investigations of snow deposition and melt patterns and of snow measuring techniques were undertaken to improve understanding of snow deposition patterns, physical changes after deposition, and variable rates of snowmelt related to the topographic structure of the watershed, climate conditions, and vegetation. To support these investigations, the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) initiated a detailed snow monitoring and measurement program early in the development of the Reynolds Creek Experimental Watershed. This snow measurement program has continued to the present and is still in operation. This effort has provided over 35 years of detailed data on snow deposition, density, and depth over RCEW that are presented in this paper.

2. Measurement Sites

Seven snow course sites were established in 1961, and one additional site was added in 1970. At one of the snow course sites, Reynolds Mountain Snow Study Site (176x07), a snow pillow was installed in 1982 (watershed locations are referenced to an arbitrary grid described by *Seyfried et al*. [this issue]). All sites are located in the high-elevation southern extent of the basin, where snow accumulation is greatest [see *Slaughter et al*., this issue, Plate 1 and Figure 1]. Table 1 gives the snow course identification numbers, along with their respective site elevation and average peak snow water equivalent (SWE) from 35 years of snow course data.

The Reynolds Mountain Snow Study Site (176x07) has been used to conduct detailed experiments on snow measurement techniques, instrumentation, and modeling. In 1970 an eighth site (163x35) with additional instrumentation similar to site 176x07 was established in an effort to extend detailed snow studies in RCEW. Site 163x35 was maintained as a fully instrumented site for several years, until it was established that there was very little difference between snow and climate conditions between 163x35 and 176x07. The additional instrumentation was then discontinued, and only the snow course at site 163x35 was continued. A more detailed discussion of all site locations and descriptions is given by *Marks et al*. [2000].

3. Methods

3.1. Snow Course Measurements

Snow water equivalent (SWE), depth, and density have been sampled at multiple locations in RCEW since 1961. These data have been collected using snow tube methods that are described by *Goodison et al*. [1981]. These methods are generally considered the standard for manual measurement of SWE, snow depth, and density. At the time the RCEW snow courses were established, the USDA ARS and Natural Resource Conservation Service (formally the Soil Conservation Service) were involved in testing and evaluating snow samplers. A transition from the Standard Federal Sampler to the Rosen sampler was begun in 1966 because the Rosen sampler showed consistently less oversampling (2.9% versus 10.2% when averaged over all conditions as reported by *Work et al*. [1965]). The Standard Federal Sampler was replaced with the Rosen sampler in 1968.

[1]Retired January 1999.

Paper number 2001WR000416.

Table 1. Snow Course 35-Year Average Peak SWE[a]

Site	Elevation, m	Average Peak SWE Date	Average Peak SWE Millimeters
163x20	2167	April 15	722
163x35	2147	April 1	644
163x98	2125	April 1	664
174x26	2078	April 1	643
176x07	2061	April 1	560
167x07	2010	April 1	319
144x62	1808	March 15	274
155x54	1743	March 1	221

[a]SWE is snow water equivalent.

3.2. Continuous Measurement of SWE With a Snow Pillow

SWE has been continuously monitored at site 176x07 using a snow pillow since late 1982. A pressure snow pillow gauge is a device similar to a large air or water mattress filled with antifreeze. As snow is deposited on this gauge, the pressure increase is related to the accumulating mass and thus to SWE. Such devices have been in use since the early 1960s but have been considered generally reliable only since the late 1970s or early 1980s.

4. Snow Data

4.1. Snow Course Data

Prior to the 1970 water year, data were not collected on a specific schedule, and not all sites were visited on the same day or the same number of times. Beginning with the 1970 water year, data have been collected approximately every 2 weeks, starting December 1 and ending on May 15, at all eight sites for at least 12 data values for each site for each water year.

The SWE and depth data show that the snow courses are separated into two groups (Table 1 and Plate 1a). Five snow courses (163x20, 163x35, 163x98, 174x26, and 176x07) are high-deposition sites, and three snow courses (144x 62, 155x54, and 167x07) are low-deposition sites. The high-deposition snow courses are high-elevation sites, ranging from 2061 m to 2167 m. Of the low-deposition sites, 144x62 (1808 m) and 155x54 (1743 m) are of lower elevation, while 167x07 (2010 m) is at an elevation similar to the high-deposition sites. The two low-elevation sites are near the lower limit of continuous snow cover in RCEW, and we would expect them to show less snow. From Plate 1 and Figure 1 of *Slaughter et al*. [this issue] we can see that site 167x07 occupies a western exposure that creates a much drier location for that elevation than the more northern exposures of the other high-elevation sites.

Average snow density shows only a small difference between

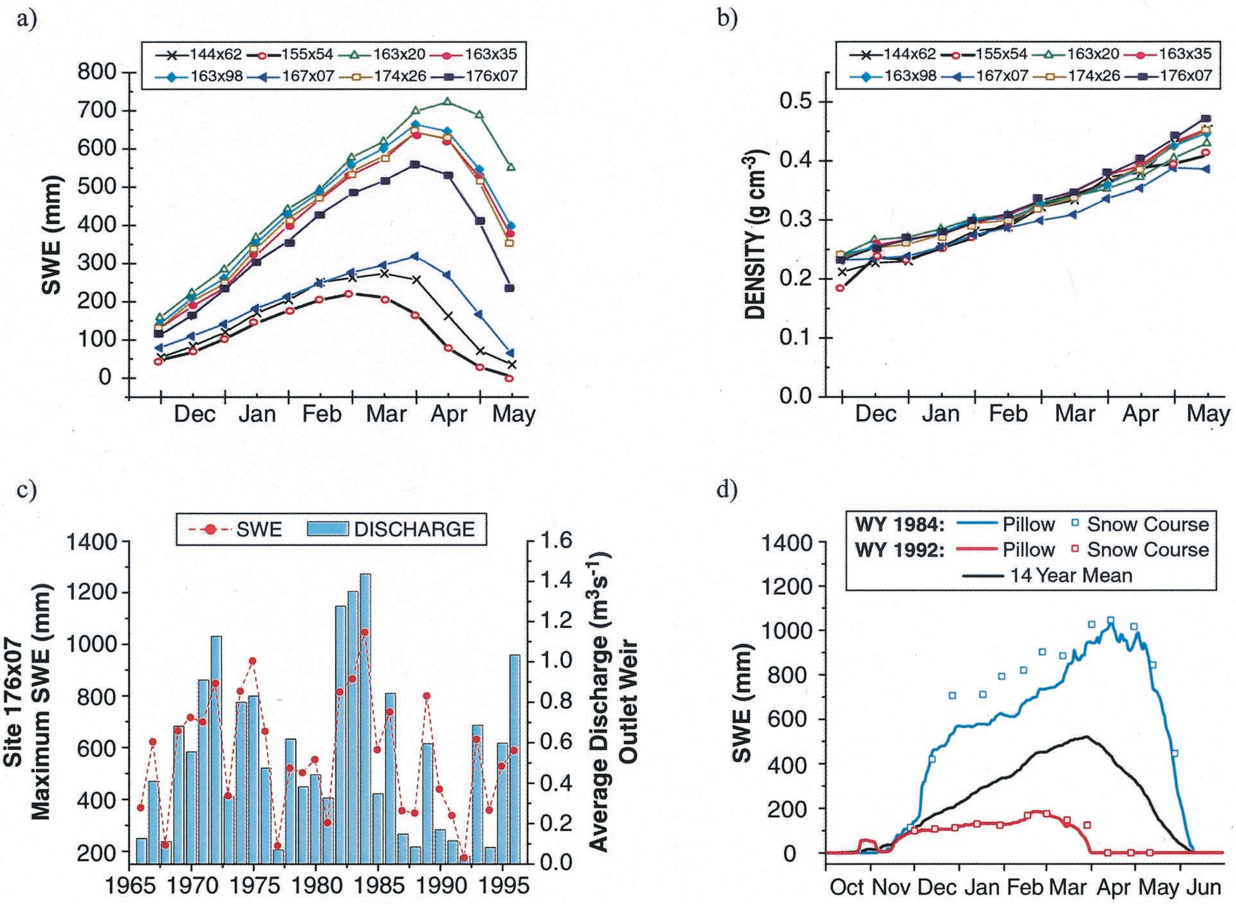

Plate 1. (a) Average snow course snow water equivalent (SWE) by measurement date for period of record (water year (WY) 1962–1996). (b) Average snow course density by measurement date for period of record (WY 1962–1996). (c) Annual maximum SWE for site 176x07 and annual stream discharge from the Outlet Weir for period of record (WY 1965–1996). (d) Snow pillow and snow course data (SWE) comparison for average conditions, the largest snow year (1984), and smallest snow year (1992).

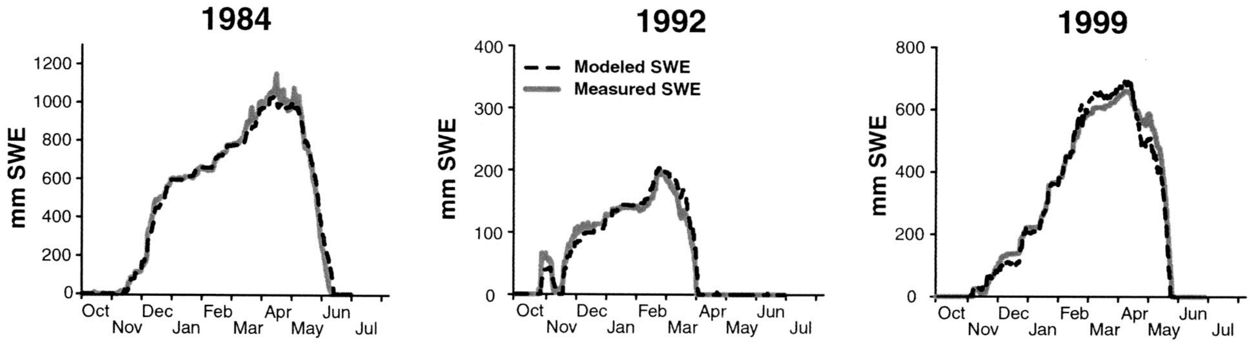

Figure 1. Comparison of simulated versus snow pillow measured SWE for three snow seasons.

sites (10–15%), though there is some separation between high- and low-deposition locations (Plate 1b). Average density steadily increases through the snow season as a result of compaction and ongoing metamorphic changes in the snowpack.

Plate 1c shows the annual maximum SWE for each year in the 35 year record at site 176x07 and annual stream discharge at the RCEW outlet weir. The strong influence that the seasonal snowcover has upon stream discharge in RCEW can be readily seen.

4.2. Snow Pillow Data

Though various snow pillows have been operated at the Reynolds Mountain Snow Study Site (176x07) since 1964, snow pillow data have been considered part of the standard snow monitoring program at RCEW only since the early 1980s. Plate 1d presents a comparison of the hourly snow pillow data with the biweekly snow course data for the 1984 and 1992 snow seasons. The 1984 snow season was the wettest in the 35 year record, while 1992 was the driest. During the 1984 snow season, snow course data are greater than pillow data until mid-April, and then they match the pillow data through melt out. During the 1992 snow season, snow course data and pillow data are in close agreement. Differences between the snow course and snow pillow during the 1984 snow season can be attributed in part to oversampling by the snow tube [*Work et al.*, 1965], bridging over the snow pillow with cold conditions during development of the snow cover in December and January [*Beaumont*, 1965], and actual differences in SWE along the snow course relative to SWE over the snow pillow.

5. Data Availability

Data from the eight snow courses and the snow pillow at site 176x07 and an electronic copy of the more detailed description of the RCEW snow data [*Marks et al.*, 2000] are available from the anonymous ftp site ftp.nwrc.ars.usda.gov maintained by the USDA Agricultural Research Service Northwest Watershed Research Center in Boise, Idaho, United States. A detailed description of data formats, access information, licensing, and disclaimers is presented by *Slaughter et al.* [this issue].

6. Examples of Data Use

Snow data from the RCEW have been used to support numerous runoff forecasting and hydrologic studies. *Hamon* [1972] used snow course data extensively to develop his dual-gage undercatch correction method. *Zuzel et al.* [1975] used snow course data from RCEW to develop optimization methods for streamflow forecasts of the RCEW and several of its subbasins. These methods were later applied to several larger basins in the northwestern United States. *Zuzel and Cox* [1975] also used snow course data to support their work in determining the relative importance of meteorological variables during snowmelt. *Springer et al.* [1984] used RCEW snow data in the development and initial testing of the Simulated Production and Utilization of Rangelands (SPUR) model, and *Wilcox et al.* [1989] used RCEW snow data to verify the ability of the SPUR model to predict snowmelt runoff.

Luce et al. [1998, 1999] used RCEW snow data for development and evaluation of snow models. Most recently, *Marks and Winstral* [2001] and *Marks et al.* [2001a, 2001b] used both snow course and snow pillow data to verify the SNOBAL snow deposition and melt model. Figure 1 shows the relationship between SNOBAL simulated and measured snow water equivalent for 3 water years in RCEW.

References

Beaumont, R. T., Mt. Hood pressure pillow snow gauge, *J. Appl. Meteorol.*, *4*, 626–631, 1965.

Goodison, B. E., H. L. Ferguson, and G. A. McKay, Measurement and data analysis, in *Handbook of Snow*, edited by D. M. Gray and D. H. Male, pp. 191–274, Pergamon, Tarrytown, N. Y., 1981.

Hamon, W. R., Computing actual precipitation, in *Distribution of Precipitation in Mountainous Areas*, *Geilo Symp.*, vol. 1, pp. 159–174, World Meteorol. Organ., Geneva, Switzerland, 1972.

Luce, C. H., D. G. Tarboton, and K. R. Cooley, The influence of the spatial distribution of snow on basin-averaged snowmelt, *Hydrol. Processes*, *12*, 1671–1684, 1998.

Luce, C. H., D. G. Tarboton, and K. R. Cooley, Subgrid parameterization of snow distribution for an energy balance snow cover model, *Hydrol. Processes*, *13*, 1921–1933, 1999.

Marks, D., and A. Winstral, Comparison of snow deposition, the snowcover energy balance, and snowmelt at two sites in a semi-arid mountain basin, *J. Hydrometeorol.*, *2*(3), 213–227, 2001.

Marks, D., K. R. Cooley, D. C. Robertson, and A. Winstral, Snow measurements and monitoring, Reynolds Creek Experimental Watershed, Idaho, USA, *Tech. Bull. NWRC 2000-5*, Northwest Watershed Res. Cent., Agric. Res. Serv., U.S. Dep. of Agric., Boise, Idaho, 2000.

Marks, D., T. Link, A. Winstral, and D. Garen, Simulating snowmelt processes during rain-on-snow over a semi-arid mountain basin, *Ann. Glaciol.*, *32*, 195–202, 2001a.

Marks, D., A. Winstral, S. Van Vactor, D. Robertson, and R. E. Davis, Simulating snow deposition, energy balance, and melt in a semi-arid watershed, in *International Symposium on Remote Sensing and Hydrology 2000*, edited by A. Rango, *IAHS Publ.*, *267*, 129–135, 2001b.

Robins, J. S., L. L. Kelly, and W. R. Hamon, Reynolds Creek in southwest Idaho: An outdoor hydrologic laboratory, *Water Resour. Res.*, *1*, 407–413, 1965.

Seyfried, M., R. Harris, D. Marks, and B. Jacob, Geographic database, Reynolds Creek Experimental Watershed, Idaho, United States, *Water Resour. Res.*, this issue.

Slaughter, C. W., D. Marks, G. N. Flerchinger, S. S. Van Vactor, and M. Burgess, Thirty-five years of research data collection at the Reynolds Creek Experimental Watershed, Idaho, United States, *Water Resour. Res.*, this issue.

Springer, E. P., C. W. Johnson, K. R. Cooley, and D. C. Robertson, Testing of the SPUR hydrology6 component on rangeland watersheds in southwestern Idaho, *Trans. ASAE*, *27*, 1040–1046, 1054, 1984.

Wilcox, B. P., K. R. Cooley, and C. L. Hanson, Predicting snowmelt runoff on sagebrush rangeland using a calibrated SPUR hydrology model, *Trans. ASAE*, *32*, 1351–1357, 1989.

Work, R. A., H. J. Stockwell, T. G. Freeman, and R. T. Beaumont, Accuracy of field snow surveys, *Tech. Rep. 163*, U.S. Army Cold Reg. Res. and Eng. Lab., Hanover, N. H., 1965.

Zuzel, J. F., and L. M. Cox, Relative importance of meteorological variables in snowmelt, *Water Resour. Res.*, *11*, 174–176, 1975.

Zuzel, J. F., D. C. Robertson, and W. J. Rawls, Optimizing long-term streamflow forecasts, *J. Soil Water Conserv.*, *30*, 76–78, 1975.

K. R. Cooley, D. Marks, D. C. Robertson, and A. Winstral, Northwest Watershed Research Center, Agricultural Research Service, U.S. Department of Agriculture, 800 Park Blvd., Suite 105, Boise, ID 83712-7716, USA. (danny@nwrc.ars.usda.gov; droberts@nwrc.ars.usda.gov; awinstra@nwrc.ars.usda.gov)

(Received September 6, 2000; revised March 7, 2001;
accepted April 16, 2001.)